RS-LiDAR-16

—— User’s Manual

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Terminologies

MSOP	Main Data Stream Output Protocol
DIFOP	Device Info Output Protocol
UCWP	User Configuration Write Protocol
Azimuth	Horizontal angle of each laser firing
Timestamp	The marker that records the system time
Header	The starting part of the protocol packet
Tail	The ending part of the protocol packet

Congratulations on your purchase of a RS-LiDAR-16 Real-Time 3D LiDAR Sensor. Please read carefully before operating the product. Wish you a pleasurable product experience with RS-LiDAR-16.

1 Safety Notices

To reduce the risk of electric shock and to avoid violating the warranty, do not open sensor body.

- **Read Instructions** - All safety and operating instructions should be read before operating the product.
- **Follow Instructions** - All operating and use instructions should be followed.
- **Retain Instructions** - The safety and operating instructions should be retained for future reference.
- **Heed Warnings** - All warnings on the product and in the operating instructions should be adhered to.
- **Servicing** - The user should not attempt to service the product beyond what is described in the operating instructions. All other servicing should be referred to RoboSense.

2 Introduction

RS-LiDAR-16, launched by RoboSense, is the first of its kind in China, world leading 16-beam miniature LiDAR product. Its main applications are in autonomous driving, robots environment perception and UAV mapping.

RS-LiDAR-16, as a solid-state hybrid LiDAR, integrates 16 laser/detector pairs mounted in a compact housing.

Unique features include:

- Measurement range of up to 150 meters
- Within 2 centimeters measurement accuracy
- Data rate of up to 320,000 points/second
- Horizontal Field of View(FOV) of 360°
- Vertical Field of View(FOV) of 30°

The compact housing of RS-LiDAR-16 mounted with 16 laser/detector pairs rapidly spins and sends out high-frequency laser beams to continuously scan the surrounding environment. Advanced digital signal processing and ranging algorithms calculate point cloud data and reflectivity of objects to enable the machine to "see" the world and to provide reliable data for localization, navigation and obstacle avoidance.

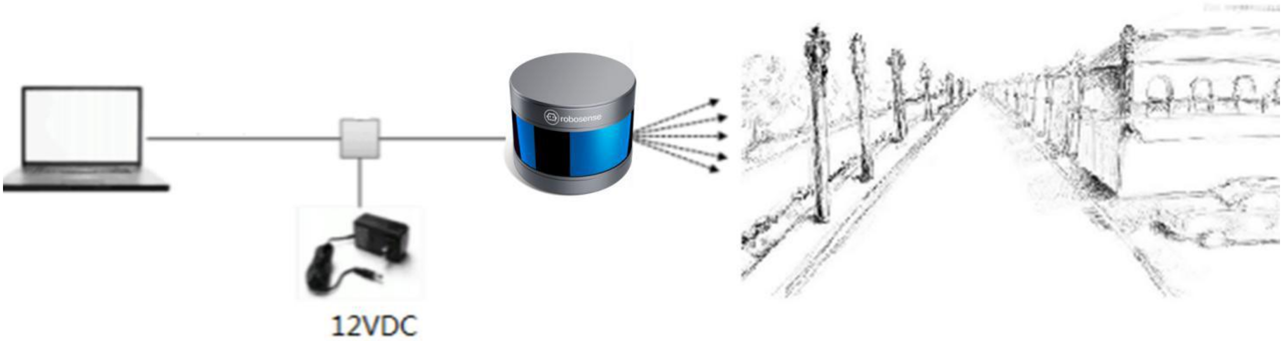


Figure 1 RS-LiDAR Imaging System

Operation of device include:

- Establish communication with RS-LiDAR-16;
- Parse the data packets for azimuth, measured distance, and reported calibrated reflectivities;
- Calculate X, Y, Z coordinates from reported azimuth, measured distance, and vertical angle;
- Store the data as needed;
- Read current device configuration data;
- Set Ethernet, time and rotational speed as needed.

3 Product Specifications

Table 1 Product Parameters

Sensor	Time of Flight Distance Measurement 16 Channels Measurement Range: 20cm to 150m (on 20% reflectivity target) Accuracy: ±2cm (typical) Field of View (Vertical): ±15.0° (30° in total) Angular Resolution (Vertical): 2° Field of View (Horizontal): 360° Angular Resolution (Horizontal/Azimuth): 0.09°(5Hz) to 0.36°(20Hz) Rotation Speed: 300/600/1200rpm (5/10/20Hz)
Laser	Class 1 Wavelength: 905nm Beam Divergence Horizontal: 3.0mrad, Vetical: 1.2mrad
Output	Data Rate: 320,000 points/second 100Mbps Ethernet UDP packet, include: Distance Rotation Angle/Azimuth Calibrated Reflectivity Synchronized Timestamp（Resolution: 1us）
Mechanical/ Electrical/ Operational	Power Consumption： 9w (typical) Operating Voltage: 12VDC（with Interface Box and Regulated Power Supply）9-32VDC Weight: 0.840Kg（without cable） Dimensions: 109mm Diameter X 82.7mm Height Protection Level: IP67 Operation Temperature: -10°C to +60°C

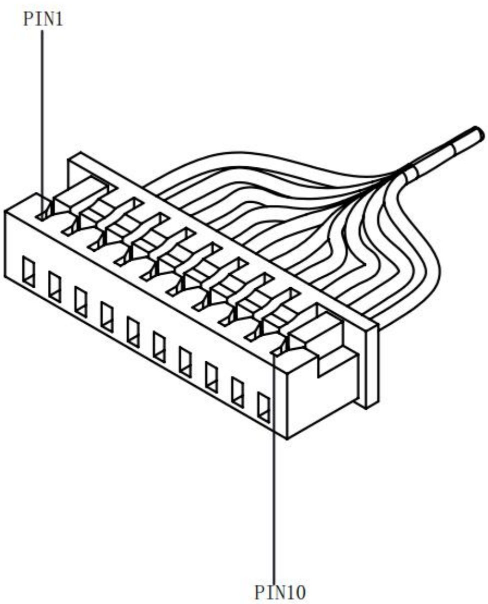
4 Connections

4.1 Power

RS-LiDAR-16 can operate with 9 to 32 volt power. But standard 12 volt power is suggested. RS-LiDAR-16 requires 9 watts (typical) of power while operating.

4.2 Electrical Configuration

RS-LiDAR-16 comes with an integral cable(power/data) that is permanently attached to the sensor and terminates at a standard SH1.1.25 wiring terminal. Figure 2 illustrates the serial pins and their properties.
To operate RS-LiDAR-16, the user should insert the SH1.25 wiring terminal to the corresponding port on the Power BOX.

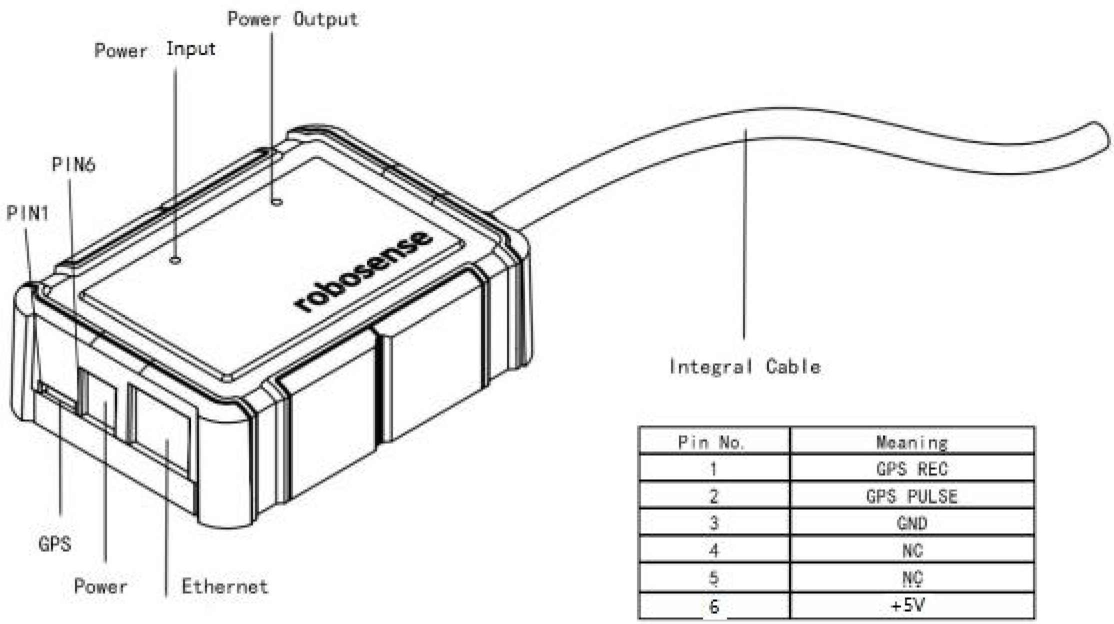


ITEN NO.	CABLE COLOR/SIZE	DESCRIPTION	QTY.
1	blue(26AWG)	GPS REC	1
2	green(26AWG)	GPS PLUSE	1
3	red(26AWG)	+12V	1
4	yellow(26AWG)	+12V	1
5	white(26AWG)	GROUND	1
6	black(26AWG)	GROUND	1
7	brown(26AWG)	ethernet RX-	1
8	brown white(26AWG)	ethernet RX+	1
9	orange(26AWG)	ethernet TX-	1
10	orange white(26AWG)	ethernet TX+	1

Figure2 Wiring Terminal and Serialized Pin

4.3 Electrical Interface

The Power BOX provides indicator leds for power, interface for power, 100Mbps Ethernet, and GPS inputs. The DC 5.5-2.1 connector for power input, RJ45 Ethernet connector for RS-LiDAR-16 data output and SH1.0-6P female connector for GPS input. (As shown in Figure 3.)



Pin No.	Meaning
1	GPS REC
2	GPS PULSE
3	GND
4	NC
5	NC
6	+5V

Figure 3 Power BOX Interfaces

Note: When RS-LiDAR-16 connects its grounding system with an external system, the external power supply system should share the same grounding system with that of the GPS.

On the Power BOX, the red light indicator means standard power input, and the green one means standard power output. The Power BOX access protection status when the red light indicator lights up and green light indicator blacks out. If the red and green light indicators light up or black out at the same time, please check for errors of the power supply. If the power supply is checked without error, the high chance is that the Power BOX is damaged. Please return damaged Power BOX to RoboSense for service.

GPS interface definition: GPS REC means GPS UART input, GPS PULSE means GPS PPS input.

Ethernet interface complies with EIA/TIA568 Standard.

Power interface adopts standard DC 5.5-2.1 connector.

5 Communications Protocols

RS-LiDAR-16 adopts UDP protocol and communicates with computer through 100Mbps Ethernet. There two different kinds of UDP output packets: MSOP packets and DIFOP packets. The UDP protocol packet in this manual is of 1290 byte long, and consists of a 1248 byte payload and a 42 byte header. The IP address and port number of RS-LiDAR-16 is set in the factory as shown in the Table 2, but can be changed by the user as needed.

Table 2 The IP Address and Port Number Set at the Factory

	IP Address	MSOP Port No.	DIFOP Port No.
RS-LiDAR-16	192.168.1.200	6699	7788
Computer	192.168.1.102		

The default MAC Address of each RS-LiDAR-16 is set in the factory . The MAC Address can be changed as needed.

To establish communication between a sensor and a computer, the IP address of the computer should be set at the same network segment of that of the sensor. By default: 192.168.1.102, subnet mask: 255.255.255.0. In case of uncertainty about the internet setting of the sensor, please set the computer subnet mask as 0.0.0.0, connect the sensor to the computer, and parse packet to get the IP and port through Wireshark.

RS-LiDAR-16 adopts 3 kinds of communications protocols to establish communication with the computer:

- MSOP(Main Data Stream Output Protocol). Distance, azimuth and reflectivity data collected by the sensor are packed and output to computer.
- DIFOP(Device Information Output Protocol). Monitor the current configuration information of the sensor.
- UCWP(User Configuration Write Protocol). User can modify some parameters of the sensor as needed.

Table 3 Protocols Adopted by RS-LiDAR-16

Protocol	Abbreviation	Function	Type	Size	Interval
Main Data Stream Output Protocol	MSOP	Scan Data Output	UDP	1248byte	~1ms
Device Information Output Protocol	DIFOP	Device Information Output	UDP	1248byte	~100Mbps
User Configuration Write Protocol	UCWP	Sensor Parameters Setting	UDP	1248byte	INF

Note：The following section describes and defines the valid payload (1248 byte) of the UDP protocol packet.

5.1 MSOP

I/O type: device output data, computer parse data.

Default port number is 6699.

MSOP outputs data information of the 3D environment in packets. Each MSOP packet is 1248 bytes long and consists of reported distance, calibrated reflectivity values, azimuth values and a time stamp.

Each RS-LiDAR-16 MSOP packet payload is 1248 byte long and consists of a 42 byte header and a 1200 byte data field containing twelve blocks of 100-byte data records and a 6 byte tail.

The basic data structure of a MSOP packet is as shown in Figure 6.

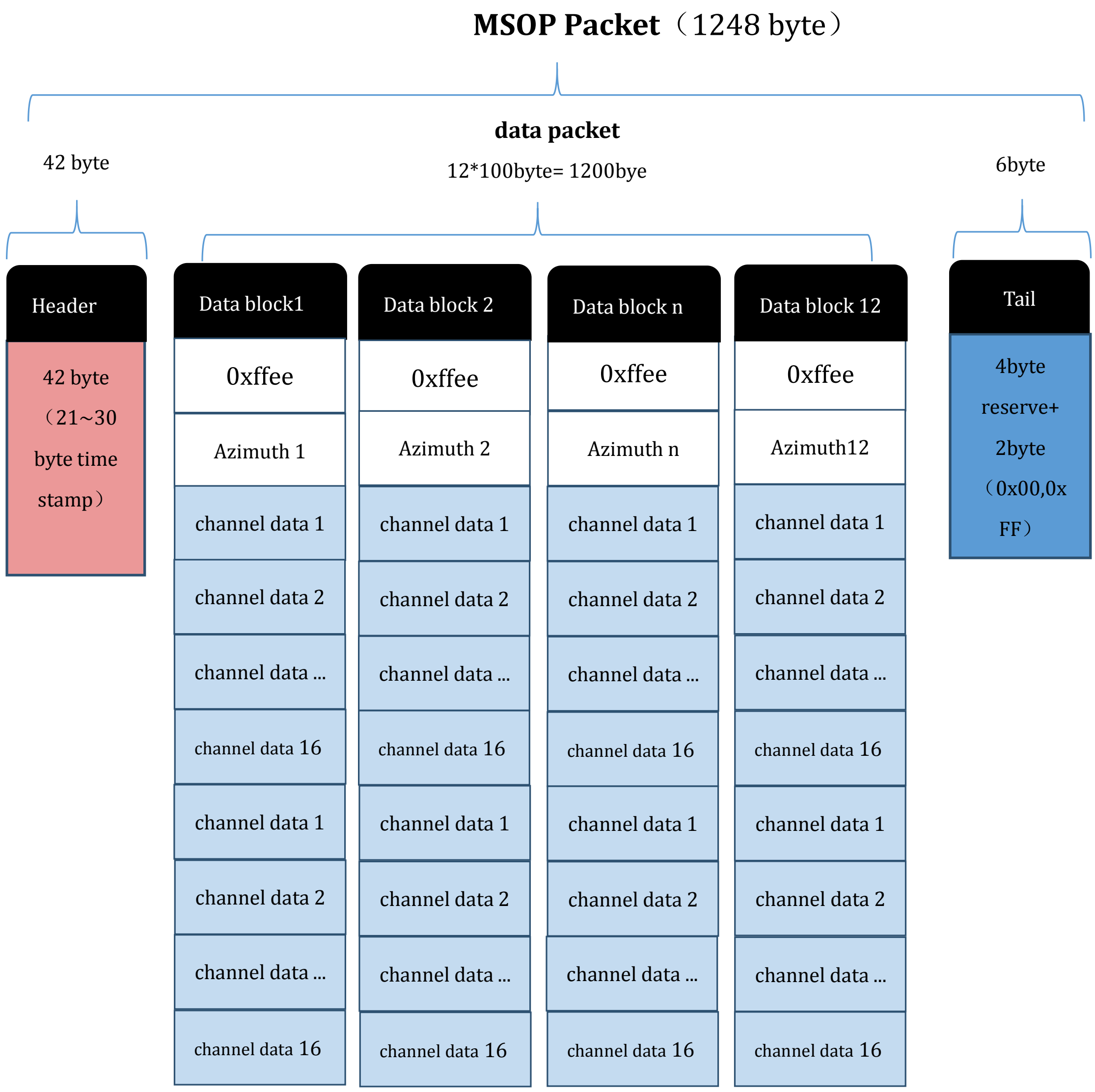


Figure 6 MSOP Packet

5.1.1 Header

The 42 byte Header marks the beginning of data blocks.
The first 8 bytes of the 42-byte data header are for header identification, among the rest 34 bytes, the 21 to 30 byte records time stamp, and the rest bytes are reserved for future updates.
The first 8 bytes of the header is defined as 0x55,0xAA,0x05,0x0A,0x5A,0xA5,0x50,0xA0.
Time stamp with a resolution of 1us records the system time. Please refer to the definition of time in Appendix B.9 and time parsing demonstration in part 3 of this section.

5.1.2 Data Field

Data field comprises data blocks that contain valid measurement data. Each data filed contains 12 blocks. Each block is 100-byte long and is a complete measurement data set. Each data block begins with a 2-byte start identifier "0xffee", then a two-byte azimuth value (rotational angle). Each azimuth value records 32 sets of channel data reported by the 32 laser channels, with data from the upper 16 channels arranged in 1 group and data from the lower 16 channels arranged in another group. (Please see Section 8 for the relationship between channel sequence and vertical angel.)

5.1.2.1 Azimuth Value

The reported azimuth is associated with the first laser firing in each sequence of 16 laser firings. The Azimuth Value is recorded by the encoder. The zero point on the encoder indicates the zero degree of azimuth value on RS-LiDAR-16. In one data block, there are 32 sets of laser data indicating two sequence of the 16 laser firings, however only every-other encoder angle is reported for alternate firing sequences. The user can choose to interpolate that unreported encoder stamp(Refer to 5.1.2.2). The resolution of Azimuth is 0.01°.

For example, in Figure 8, the azimuth value is calculated through the following steps:
Get azimuth values: 0x00，0x44
Combine to a 16 bit, unsigned integer: 0x0044
Convert to decimal: 68
Divided by 100
Result: 0.68°

Hence the firing angle is 0.68°

Note: the position of 0° on sensor is the Y axis positive direction in Figure 9.

5.1.2.2 Azimuth Value Interpolation

Because the RS-LIDAR-16 reports the azimuth value for every-other firing sequence, it's helpful to interpolate the un-reported azimuth. There are several ways to interpolate the un-reported azimuth, but the one given below is simple and straight forward.

Consider a single data packet. The time between the first firing of the first sequence of sixteen firings (Data Block 1) and the first firing of the third sequence of sixteen laser firings (Data Block 2) is ~100.0μs. If you assume the rotation speed over that short interval is constant, you can assume the azimuth of the (N+1) set of sixteen laser firings is halfway between the azimuth reported with the Nth set of 16 laser firings and the azimuth reported with the (N+2) set of laser firings.

Below is pseudo-code that performs the interpolation. The code checks to see if the azimuth rolled over from 359.99° to 0° between firing sequence N and N+2.
In the example below, N=1.

```
// First, adjust for a rollover from 359.99° to 0°
If (Azimuth[3] < Azimuth[1])
    Then Azimuth[3]:= Azimuth[3]+360;
Endif;
// Perform the interpolation
Azimuth[2]:=Azimuth[1]+((Azimuth[3]-Azimuth[1])/2);
// Correct for any rollover over from 359.99° to 0°
If (Azimuth[2]>360)
    Then Azimuth[2]:= Azimuth[2]-360;
Endif
```

5.1.2.3 Channel Data

Channel data contains 3 bytes, with the upper 2 bytes store distance information, and the lower 1 byte contains reflectivity data. The structure of channel data is as shown in Table 4.

Table 4 Channel Data

Channel Data N （3 bytes）		
2 bytes Distance		1 byte Reflectivity
Distance1 [16:8]	Distance2 [7:0]	Reflectivity

The 2-byte distance data is set in centimeter. The distance accuracy is 1 centimeter.
Reflectivity data records relative reflectivity (more definition on reflectivity, please refer to description on calibrated reflectivity in Section 9 of this manual). Reflectivity data reveals the reflectivity performance of the system in real measurement environments, it can be used in distinguishing different materials.

The following shows how to parse channel data.

In the case of Figure 8, the distance information is calculated by:

Get distance values: 0x06 ,0x42
Actual distance value: 0x06 , 0x42
Combine distance bytes to a 2-byte, unsigned integer: 0x0642
Convert to decimal: 1602
Divided by 100
Result: 16.02m
Hence the distance measured is 16.02m.

5.1.3 Tail

The tail is 6 bytes long, with 4 bytes unused and reserved for information, and the other 2 byte as: 0x00, 0xFF.

5.1.4 Demonstration Data

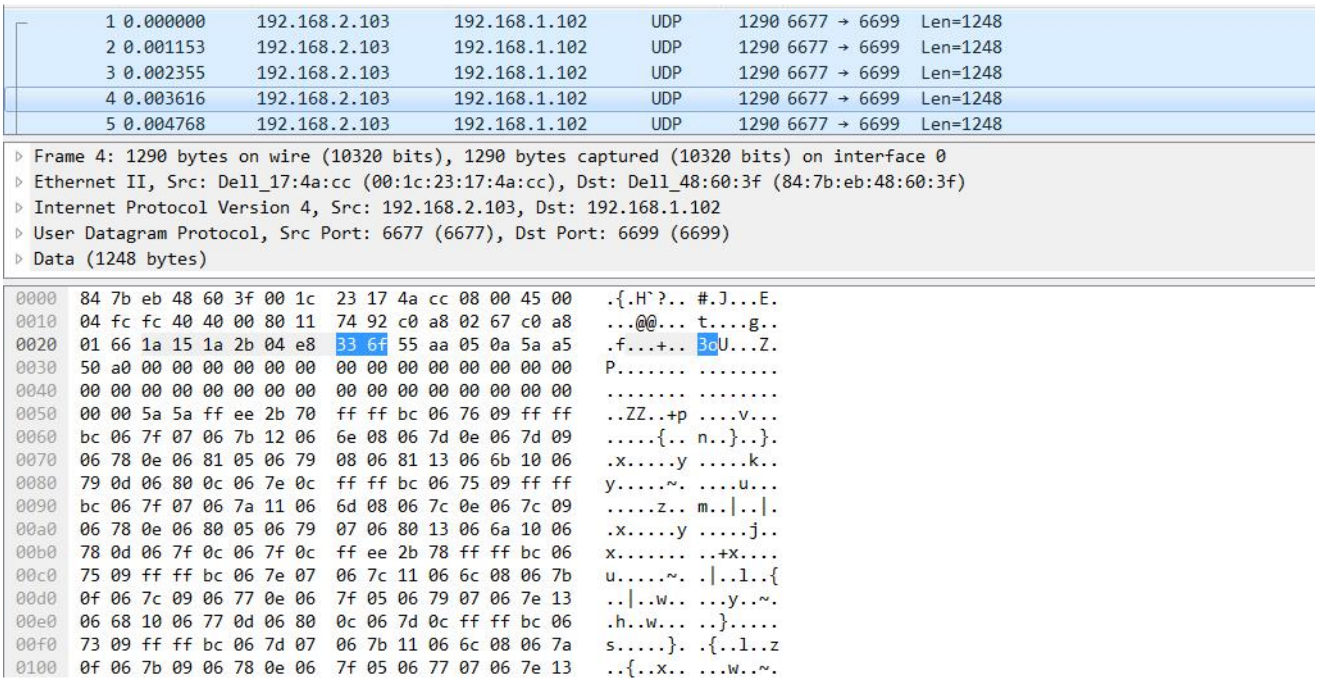


Figure 7 MSOP packet

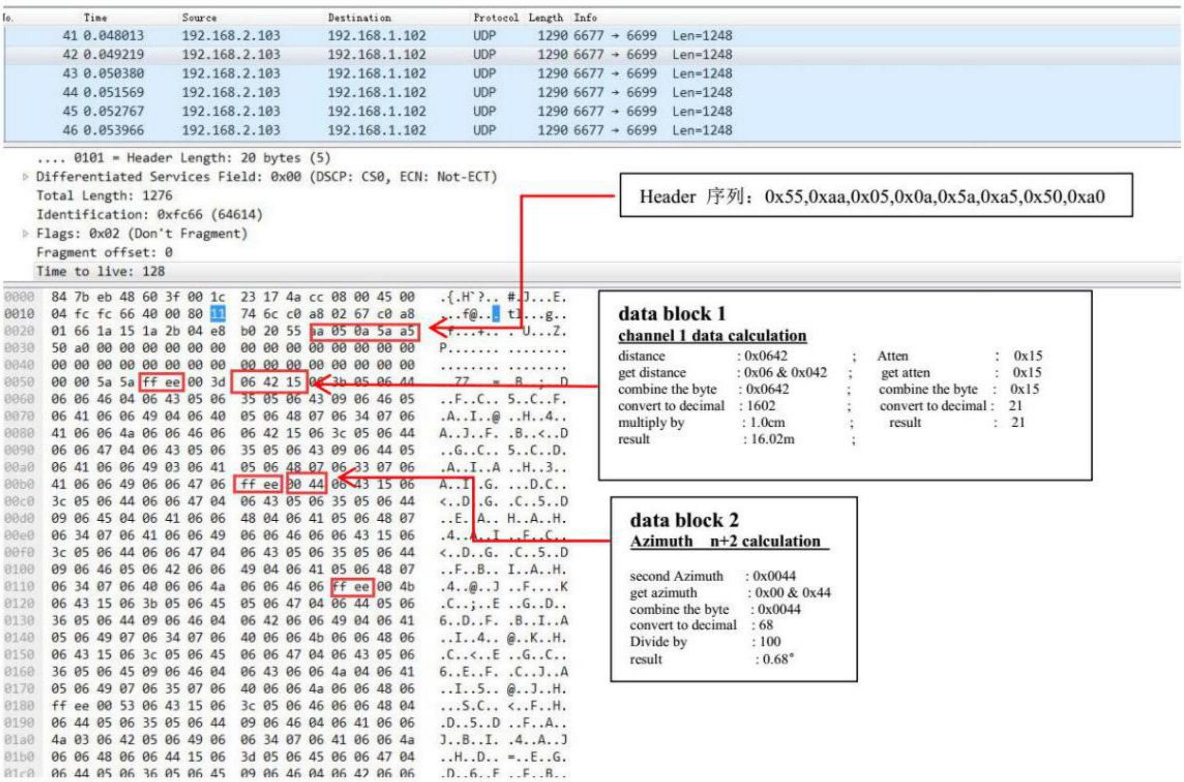


Figure 8 Data Block

5.2 DIFOP

I/O type： device output, computer read.

Default port number is 7788.

DIFOP is a protocol that reports and outputs only device information including the device serial number, firmware version, driver compatibility, internet setting, calibration data, electrical machine setting and operation status, fault detection information to users. It is a viewer for users to get comprehensive details about the device.

Each DIFOP packet is 1248 byte long, and comprises a 8 byte Header, a 1238 byte data field, and a 2 byte tail.

The structure of DIFOP is as shown in Table 5.

Table 5 DIFO Packet

	No.	Information	Offset	Length（byte）
Header	0	DIFOP header	0	8
Data	1	motor rotation speed (MOT_SPD)	8	2
	2	Ethernet(ETH)	10	26
	3	corrected static base (COR_STATIC_BASE)	36	2
	4	motor phase lock(MOT_PHASE)	38	2
	5	top board firmware version(TOP_FRM)	40	5
	6	bottom board firmware version(BOT_FRM)	45	50
	7	reserved	50	50
	8	corrected pitch (COR-PITCH)	100	64
	9	reseved	164	128
	10	serial number(SN)	292	6
	11	reserved	298	3
	12	Upper computer compatibility	301	2
	13	UTC time(UTC_TIME)	303	10
	14	operation status(STATUS)	313	18
	15	reserved	331	11
	16	fault diagnosis(FALT_DIGS)	342	40
	17	GPSRMC	382	86
	18	corrected static(COR_STATIC)	468	697
	19	reserved	1165	81
Tail	20	tail	1246	2

Note: The Header(the DIFOP identifier) in the table above is 0xA5,0xFF,0x00,0x5A,0x11,0x11,0x55,0x55, among which the first 4 byte 0xA5,0xFF,0x00,0x5A is the sequence to identify the packet.

The tail is 0x0F,0xF0.

For definition of information registers as well as their usage, please check more details in part 2, section 10 of this manual.

5.3 UCWP

I/O type: computer writes into the device.

Function: user can reconfigure Ethernet connection, time and some parameters of the device.

Each UCWP Packet is 1248 byte long, and is comprised of a 8-byte Header, a 1238-byte data field and a 2-byte Tail.

The UCWP packet structure is as shown below:

Table 6 UCWP Packet

	No.	Info	Offset	Length（byte）
Header	0	UCWP header	0	8
Data	1	motor rotation speed	8	2
	2	Ethernet	10	26
	3	time	36	10
	4	reserved	46	2
	5	motor phase lock	48	2
	6	reserved	50	1196
Tail	7	tail	1246	2

Note: The Header(UCWP identifier) in the table above is 0xAA,0x00,0xFF,0x11,0x22,0x22,0xAA,0xAA, among which, the first 4 bytes 0xAA,0x00,0xFF,0x11 forms the sequence to identify the packet.
The Tail is 0x0F,0xF0.

Statement: RS-LiDAR-16 doesn't RTC system to support operation while power is off. In the case of no GPS or GPS signal, it is imperative to write time into the device through a computer, or it will use a default system time for clock.
Refer to Part 2, Section 10 of this manual for details on Ethernet, Time, Motor Rotation Speed and Motor Phase Lock.
Below is and example to configure the RS-LIDAR-16 :
LiDAR IP: 192.168.1.105,
Destination PC IP: 192.168.1.225,
MAC_ADDR: 001C23174ACC
MSOP port: 6688
DIFOP port: 8899
Time: 09:45:30:100:200, March 10, 2017
Rotation speed: 600rpm
Motor phase lock: 90 degree

User can reset the above information by following the example in Table 7.

Table 7 Resetting Example

Information	Content	Setting	Length（byte）
Header		0xAA,0x00,0xFF,0x11, 0x22,0x22,0xAA,0xAA	8
Rotate Speed	1200rpm	0x04 0xB0	2
LiDAR IP （LIDAR_IP）	192.168.1.105	0xC0 0xA8	4

		0x01 0x69	
Destination PC IP （DEST_PC_IP）	192.168.1.225	0xC0 0xA8 0x01 0xE1	4
Device MAC Address （MAC_ADDR）	001C23174ACC	0x00,0x1C,0x23, 0x17,0x4A,0xCC	6
MSOP Port（port1）	6688	0x1A20	2
MSOP Port（port2）	6688	0x1A20	2
DIFOP Port（port3）	8899	0x22C3	2
DIFOP Port（port4）	8899	0x22C3	2
port5~port6	00,00,00,00，	0x00,0x00,0x00,0x00，	4
UTC_TIME	Year:2017 Month:3 Day:10 Hour:9 Minute:45 Second:30 Millisecond: 100 Microsecond: 200	0x11 0x03 0x0A 0x09 0x2D 0x1E 0x00,0x64 0x00,0xC8	10
Others	reserved	0x00	2
Motor Phase Lock	90	0x005A	2
Others	reserved	0x00	1196
Tail		0x0F,0xF0	2

While setting the device and computer according to this protocol, it is imperative to set all the information listed in the table above. Addressing or writing in with part of the information will lead to invalid setting. The function refreshes the moment the correspondent parameter is changed, but the network parameters only take effect when the next initialization of device is started.

RSVIEW provide the

6 GPS Synchronization

RS-LiDAR-16 supports external GPS receiver connections. With GPS connections, we can synchronize the RS-LiDAR-16 system time and also pack the GPSRMC message into DIFOP packets.

6.1 GPS Synchronization Theory

The GPS receiver keeps generating synchronization Pulse Per Second (PPS) signal and GPSRMC message and send them to the sensor. It takes 20ms to 200ms to generate a PPS signal, and the GPSRMC message should be received within 500ms after the PPS signal is generated.

6.2 GPS Usage

The GPS interface on the Power Box is SH1.0-6P female connector, the pin definition is as shown in Figure 3.
Pin GPS REC receive the data that is 3.3V TTL standard from GPS module serial port.
Pin GPS PULSE receive the PPS from GPS module.
Pin +5V can supply the power for GPS module. (Please do not connect the GPS into the +5V pin if the GPS is 3.3V power supply)
Pin GND provide the ground connection for GPS module.
The GPS module should set to 9600bps baud rate, 8 bit data bit, no parity and 1 stop bit. RS-LiDAR-16 only read the GPSRMC message from GPS module., the GPSMRC message format is shown as below:

$GPRMC,<1>,<2>,<3>,<4>,<5>,<6>,<7>,<8>,<9>,<10>,<11>,<12>*hh

<1> UTC time
<2> validity - A-ok, V-invalid
<3> Latitude
<4> North/South
<5> Longitude
<6> East/West
<7> Ground Speed
<8> True course
<9> UTC date
<10> Variation
<11> East/West
<12> Mode (A/D/E/N=)
*hh checksum from $ to *

Different GPS module may send out different length GPSRMC message, the RS-LiDAR-16 reserve 86byte space for GPSRMC message, so it can be compatible with the majority GPS module in the market.

7 Point Cloud

7.1 Coordinate Mapping

RS-LiDAR-16 exports data packet that contains azimuth value and distance data. But to present a 3 dimensional point cloud effect, a transformation of the azimuth value and distance data into x, y, z coordinates in accordance to Cartesian Coordinate System is necessary. The function of how to transfer the information is as shown below:

$$\begin{cases} x = r\cos(\omega)\sin(\alpha); \\ y = r\cos(\omega)\cos(\alpha); \\ z = r\sin(\omega); \end{cases}$$

Here r is the reported distance, ω is the vertical/elevation angle of the laser(which is fixed and is given by the Laser ID), and α is the horizontal angle/azimuth reported at the beginning of every other firing sequence. x, y, z values are the projection of the polar coordinates on the XYZ Cartesian Coordinate System.

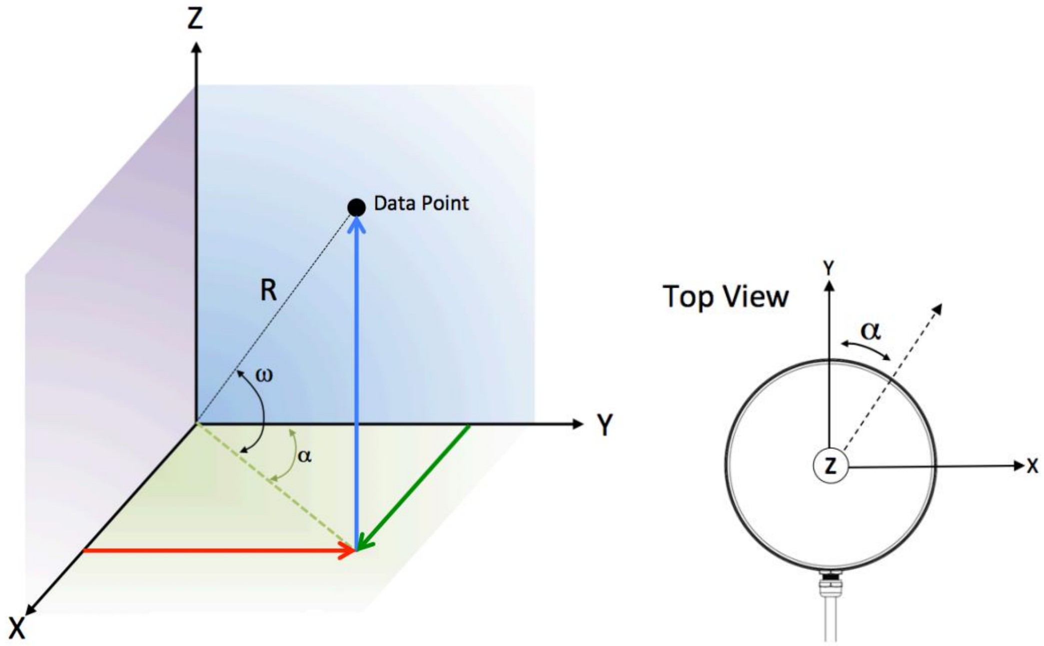


Figure 9 Coordinate Mapping

Note 1： In the RS-LiDAR-16 ROS package, we use a coordinate transformation by default: ROS-X axis is the Y axis as Figure 9, while ROS-Y axis is -X axis as Figure 9, Z axis keep the same.

Note 2: The origin of the LiDAR coordinate is defined at the center of the LiDAR structure, with 39.8mm high to the bottom of the LiDAR.

7.2 Point Cloud Presentation

In a circular arena, as the RS-LiDAR-16 rotates, the scanning path of the 16 laser beams plots 16 conical scanning surfaces with 8 face upward and 8 face downward, and the point cloud produced are the section line between these conical surfaces and the floor which are circles. While in non-circular environments, the point cloud produced are the section lines of the conical surfaces and the surface of objects. Therefore, in an rectangular environment, the section lines of the conical surfaces and the rectangular planes are hyperbolas as shown in Figure 10.

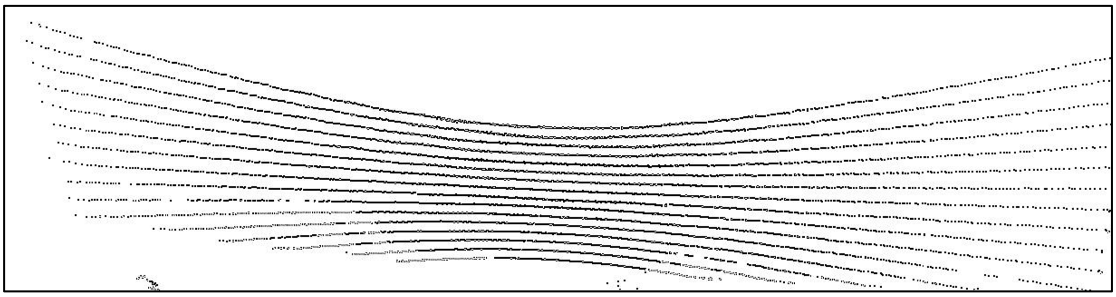


Figure 10 Contour lines plotted on X, Z coordinates

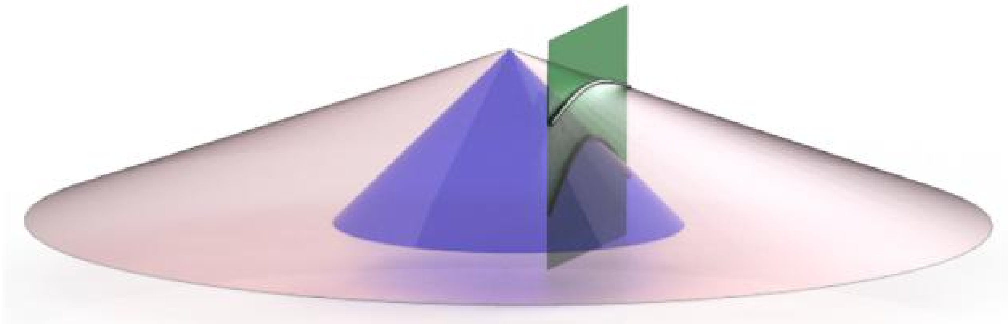


Figure 11 RS-LiDAR-16 Scanning Illustration

The hyperbolas contour lines phenomenon can also be explain by transforming polar coordinates into orthogonal coordinates. As shown in Figure 12, we deduced the function of a hyperbolas $\frac{z^2}{(y\tan(\omega))^2}-\frac{x^2}{y^2}=1$. In Figure 13, When y and ω are definite values, $\frac{z^2}{(y\tan(\omega))^2}-\frac{x^2}{y^2}=1$ indicates a hyperbola with focus on z coordinate. When y is a definite value, as ω gains in value, the asymptote slope and eccentricity will decline thereof, which resulted a more curved hyperbola. On the contrary, as α loses in value, a more flat hyperbola is resulted. When α is a definite value, as y gains in value, asympote of the same angle presents same slope. Value of y determines the width between scanning contours.

$$x = r\cos(\omega)\cos(\alpha);$$
$$y = r\cos(\omega)\sin(\alpha);$$
$$z = r\sin(\omega);$$

$$x^2 + y^2 = z^2\cos^2(\omega)/\sin^2(\omega)$$

$$\frac{z^2}{(y\tan(\omega))^2}-\frac{x^2}{y^2}=1$$

Figure 12 Hyperbolic Function

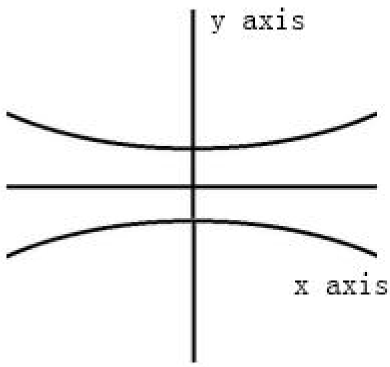


Figure 13 Hyperbola

8 Laser Channels and Vertical Angles

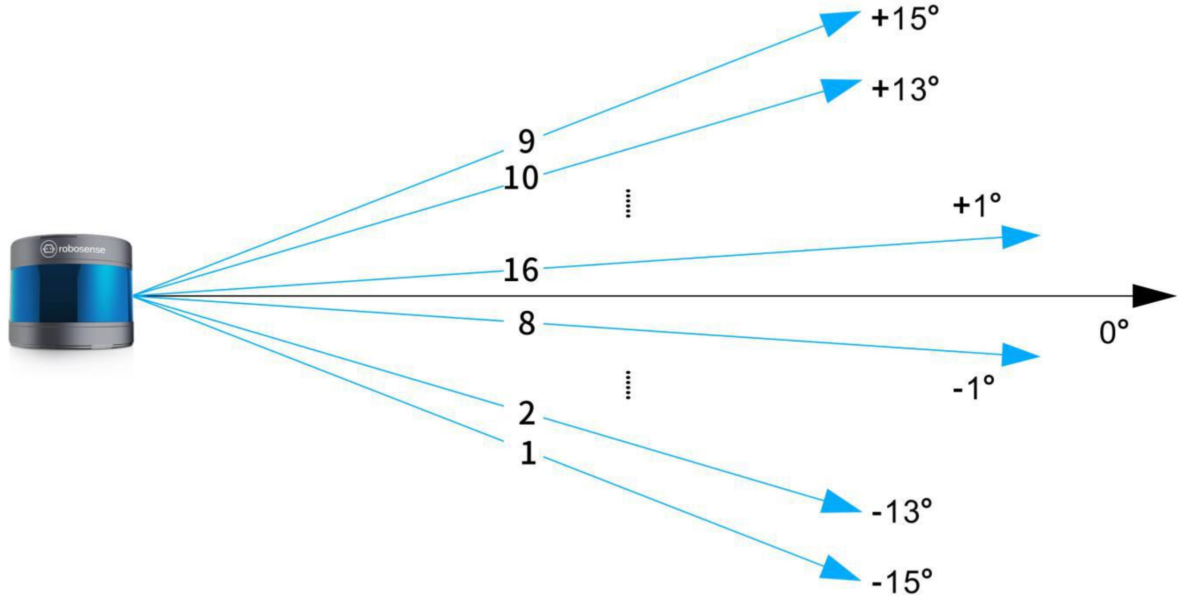


Figure 14 RS-LiDAR-16 Laser Channels and Vertical Angles

RS-LiDAR-16 has a vertical field of view of -15° to +15° with a eventful interval of 2 degrees. The 16 laser heads also called as 16 channels. The laser channels and their designated vertical angles are as shown in the Table 8. However, a lot of elements in the assembling process will lead to slight divergence between the actual angle of laser channels and their ideal vertical angle. The calibrated vertical angle can be found from the U disk (path: configuration_data/angle.csv).

Table 8 Laser Channel Number and Their Designated Vertical Angle.

Laser Channel No.	Ideal Vertical Angle
1	-15
2	-13
3	-11
4	-9
5	-7
6	-5
7	-3
8	-1
9	+15
10	+13
11	+11
12	+9

13	+7
14	+5
15	+3
16	+1

Every sequence of 16 laser firings consumes 50us.

9 Calibrated Reflectivity

RS-LiDAR-16 produces calibrated reflectivity data of objects. Reflectivity of object is largely determined by the property of objects. Reflectivity therefore is an important information for LiDAR to distinguish objects.

RS-LiDAR-16 reports reflectivity values from 0 to 255 with 255 being the reported reflectivity for an ideal reflector. Diffuse reflection reports values from 0 to 100, with the weakest reflectivity reported from black objects and strongest reflectivity reported from white object. Retro- reflector reports values from 101 to 255.

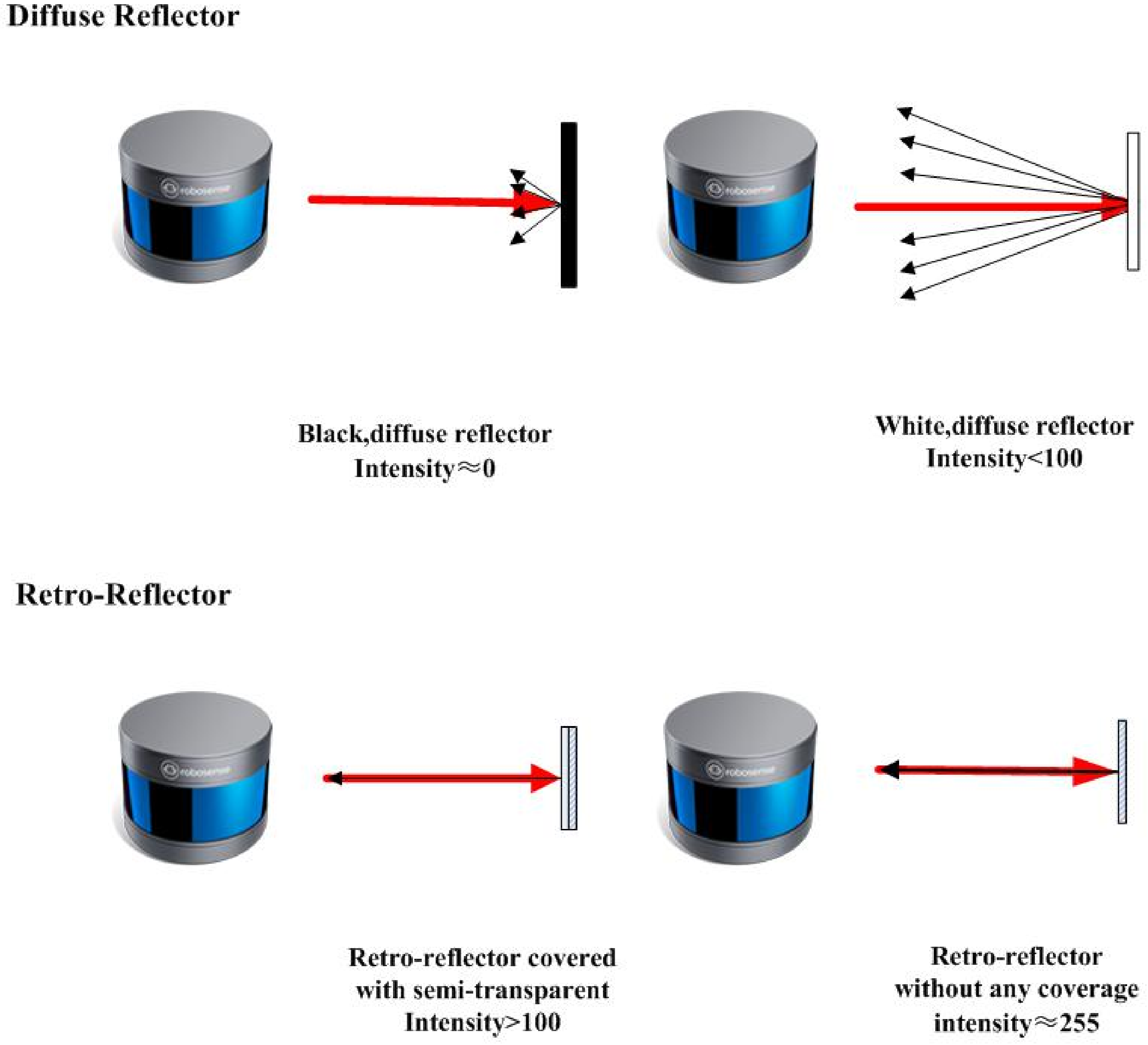


Figure 15 Reflector Types

To calculate each point intensity, we need use the intensity value from MOSP packet and the values from the calibrated reflectivity file. The calibrated reflectivity file can be found from the U disk (path: configuration_data/curves.csv). The calculate code is suggested to refer to the function calibrateIntensity( ) in rawdata.cc from RS-LiDAR-16 ROS package.

Appendix A ▪ Point Time Calculate

In a MSOP packet, there are 12 blocks, each block has two sequence for the whole 16 laser firings, so in a MOSP packet, there are 24 groups for the whole 16 laser firings. All sixteen lasers are fired and recharged every 50.0µs. The cycle time between firing is 3µs. There are 16 firings (16 x 3µs) followed by a short period of 2µs. Therefore, the timing cycle to fire and recharge all 16 lasers is given by ((16 x 2.304µs) + (1 x 2µs)) = 50µs.

Set the channel number data_index is 1-16, firing sequences is 1-24. Because the time stamp is the time of the first data point in the packet, you need to calculate a time offset for each data point and then add that offset to the time stamp.

Time offset is:

Time_offset = 50us * (sequence_index -1) + 3us * (data_index-1)

To calculate the exact point time, add the TimeOffset to the timestamp:

Exact_point_time = Timestamp + Time_offset

Table 9 Time Offset for Each Channel

	Channel ID	Data Block											
		1	2	3	4	5	6	7	8	9	10	11	12
First Firing	1	0.00	100.00	200.00	300.00	400.00	500.00	600.00	700.00	800.00	900.00	1000.00	1100.00
	2	3.00	103.00	203.00	303.00	403.00	503.00	603.00	703.00	803.00	903.00	1003.00	1103.00
	3	6.00	106.00	206.00	306.00	406.00	506.00	606.00	706.00	806.00	906.00	1006.00	1106.00
	4	9.00	109.00	209.00	309.00	409.00	509.00	609.00	709.00	809.00	909.00	1009.00	1109.00
	5	12.00	112.00	212.00	312.00	412.00	512.00	612.00	712.00	812.00	912.00	1012.00	1112.00
	6	15.00	115.00	215.00	315.00	415.00	515.00	615.00	715.00	815.00	915.00	1015.00	1115.00
	7	18.00	118.00	218.00	318.00	418.00	518.00	618.00	718.00	818.00	918.00	1018.00	1118.00
	8	21.00	121.00	221.00	321.00	421.00	521.00	621.00	721.00	821.00	921.00	1021.00	1121.00
	9	24.00	124.00	224.00	324.00	424.00	524.00	624.00	724.00	824.00	924.00	1024.00	1124.00
	10	27.00	127.00	227.00	327.00	427.00	527.00	627.00	727.00	827.00	927.00	1027.00	1127.00
	11	30.00	130.00	230.00	330.00	430.00	530.00	630.00	730.00	830.00	930.00	1030.00	1130.00
	12	33.00	133.00	233.00	333.00	433.00	533.00	633.00	733.00	833.00	933.00	1033.00	1133.00
	13	36.00	136.00	236.00	336.00	436.00	536.00	636.00	736.00	836.00	936.00	1036.00	1136.00
	14	39.00	139.00	239.00	339.00	439.00	539.00	639.00	739.00	839.00	939.00	1039.00	1139.00
	15	42.00	142.00	242.00	342.00	442.00	542.00	642.00	742.00	842.00	942.00	1042.00	1142.00
	16	45.00	145.00	245.00	345.00	445.00	545.00	645.00	745.00	845.00	945.00	1045.00	1145.00
Second Firing	1	50.00	150.00	250.00	350.00	450.00	550.00	650.00	750.00	850.00	950.00	1050.00	1150.00
	2	53.00	153.00	253.00	353.00	453.00	553.00	653.00	753.00	853.00	953.00	1053.00	1153.00
	3	56.00	156.00	256.00	356.00	456.00	556.00	656.00	756.00	856.00	956.00	1056.00	1156.00
	4	59.00	159.00	259.00	359.00	459.00	559.00	659.00	759.00	859.00	959.00	1059.00	1159.00
	5	62.00	162.00	262.00	362.00	462.00	562.00	662.00	762.00	862.00	962.00	1062.00	1162.00
	6	65.00	165.00	265.00	365.00	465.00	565.00	665.00	765.00	865.00	965.00	1065.00	1165.00
	7	68.00	168.00	268.00	368.00	468.00	568.00	668.00	768.00	868.00	968.00	1068.00	1168.00
	8	71.00	171.00	271.00	371.00	471.00	571.00	671.00	771.00	871.00	971.00	1071.00	1171.00
	9	74.00	174.00	274.00	374.00	474.00	574.00	674.00	774.00	874.00	974.00	1074.00	1174.00
	10	77.00	177.00	277.00	377.00	477.00	577.00	677.00	777.00	877.00	977.00	1077.00	1177.00
	11	80.00	180.00	280.00	380.00	480.00	580.00	680.00	780.00	880.00	980.00	1080.00	1180.00
	12	83.00	183.00	283.00	383.00	483.00	583.00	683.00	783.00	883.00	983.00	1083.00	1183.00
	13	86.00	186.00	286.00	386.00	486.00	586.00	686.00	786.00	886.00	986.00	1086.00	1186.00
	14	89.00	189.00	289.00	389.00	489.00	589.00	689.00	789.00	889.00	989.00	1089.00	1189.00
	15	92.00	192.00	292.00	392.00	492.00	592.00	692.00	792.00	892.00	992.00	1092.00	1192.00
	16	95.00	195.00	295.00	395.00	495.00	595.00	695.00	795.00	895.00	995.00	1095.00	1195.00

Appendix B ▪ Information Registers

Here are definitions and more details on information registers as mentioned in Section 5.

B.1 Motor（MOT_SPD）

Motor Speed(2 bytes in total)						
Byte No.	byte1	byte2				
Function	MOTOR					

Register description:

（1）This register is used to set the rotation direction and rotation speed.

（2）The data storage format adopts big endian format.

（3）Supported rotation speed:

(byte1==0x04) && (byte2==0xB0)　speed 1200rpm, clockwise rotation;

(byte1==0x02) && (byte2==0x58)　speed 600rpm, clockwise rotation;

(byte1==0x01) &&(byte2==0x2C)　speed 300rpm, clockwise rotation;

If set with data other than the above described, the rotation speed of the motor is 0.

B.2 Ethernet（ETH）

Ethernet (26 bytes in total)								
Byte No.	byte1	byte2	byte3	byte4	byte5	byte6	byte7	byte8
Function	LIDAR_IP				IP_DEST			
Byte No.	byte9	byte10	byte11	byte12	byte13	byte14	byte15	byte16
Function	MAC_ADDR						port1	
Byte No.	byte17	byte18	byte19	byte20	byte21	byte22	byte23	byte24
Function	port2		port3		port4		port5	
Byte No.	byte25	byte26						
Function	Port6							

Register description:

（1）LIDAR_IP is the LiDAR source IP address, it takes 4 bytes.

（2）DEST_PC_IP is the destination PC IP address, it takes 4 bytes.

（3）MAC_ADDR is the LiDAR MAC Address.

（4）port1~port6 signals the number of ports. Port1 and port2 are the MSOP packet ports, they should be set to the same number. Port3 and port4 are the DIFOP packet ports, they should be set to the same number.

B.3 Motor Phase Lock (MOT_PHASE)

Motor Phase Lock（2bytes in total）

Byth No.	byte1	byte2				
Function	MOT_PHASE					

Register description: It can be used to adjust the phase of the motor rotation with the GPS PPS together. The value can be set from 0 to 360. The data storage format adopts big endian format. For example: the byte1=1, byte2=14, so the motor phase should be 1*256+14 = 270.

B.4 TOP Board Firmware (TOP_FRM)

TBD

B.5 Bottom Board Firmware (TOP_FRM)

TBD

B.2 Corrected Pitch (COR_PITCH)

Corrected Pitch（48 bytes in total）									
Byte No.	byte1	byte2	byte3	byte4	byte5	byte6	byte7	byte8	Byte9
Function	Channel 1			Channel 2			Channel 3		
Byte No.	byte10	Byte11	Byte12	Byte14	Byte14	Byte15	Byte16	Byte17	Byte18
Function	Channel 4			Channel 5			Channel 6		
Byte No.	byte19	byte20	Byte21	Byte22	Byte23	Byte24	Byte25	Byte26	Byte27
Function	Channel 7			Channel 8			Channel 9		
Byte No.	Byte28	byte29	byte30	Byte31	Byte32	Byte33	Byte34	Byte35	Byte36
Function	Channel 10			Channel 11			Channel 12		
Byte No.	Byte37	Byte38	byte39	byte40	Byte41	Byte42	Byte43	Byte44	Byte45
Function	Channel 13			Channel 14			Channel 15		
Byte No.	Byte46	Byte47	Byte48						
Function	Channel 16								

Register description:

（1）The storage format of corrected pitch data adopts big endian format.

（2）LSB = 0.0001°

（2）The value of the pitch is unsigned integer. Channel 1 to Channel 8 pitches downwards, channel 9 to channel 16 pitches upwards.

For example, the calculation of vertical angle of channel 9:

byte1 = 0，byte2 = 39，byte3 = 16,

cor_pitch_9: （0*（256^2）+ 39*（256^1）+16）*0.0001 = 1°

***At currently, this register is left to N/A, so we need find the angle from U disk (path: configuration_data/angle.csv)

B.7 Serial Number（SN）

Serial Number（6 bytes in total）						
Byte No.	1byte	2byte	3byte	4byte	5byte	6byte
Function	SN					

The Serial Number of each device adopts the same format as the MAC_Address, namely, a 6-byte hexadecimal number.

B.8 Software Version（SOFTWARE_VER）

Software Version（2 bytes in toatal）						
Byte No.	byte1	byte2				
Function	SOFTWARE_VER					

B.9 UTC Time（UTC_TIME）

UTC Time (8 bytes in total）								
Byte No.	byte1	byte2	byte3	byte4	byte5	byte6	byte7	byte8
Function	year	month	day	hour	min	sec	ms	
Byte No.	byte9	byte10						
Function	us							

Register description:

1) Year

reg name：set_year								
Byte No.	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	set_year[7:0]：data 0~255 corresponds year 2000 to year 2255.							

2) month

reg name：set_month								
Byte No.	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	reserve	reserve	reserve	reserve	set_month[3:0]：1~12 month			

3) Day

reg name：set_day								
Byte No.	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	reserve	reserve	reserve	set_day[4:0]：1~31 day				

4) Hour

reg name：set_hour

Byte No.	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	reserve	reserve	reserve	set_hour[4:0]：0~23 hour				

5) Min

reg name：set_min								
Byte No.	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	reserve	reserve	set_min[5:0]：0~59 min					

6) Sec

reg name：set_sec								
Byte No.	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	reserve	reserve	set_sec[5:0]：0~59 sec					

7) Ms

reg name：set_ms								
Byte No.	bit15	bit14	bit13	bit12	bit11	bit10	bit9	bit8
Function	reserve	reserve	reserve	reserve	reserve	reserve	ms[9:8]	
Byte No.	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	set_ms[7:0]							

Note：set_ms[9:0] value：0~999

8) Us

reg name：set_us								
Byte No.	bit15	bit14	bit13	bit12	bit11	bit10	bit9	bit8
Function	reserve	reserve	reserve	reserve	reserve	reserve	us[9:8]	
Byte No.	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	set_us[7:0]							

Note：set_us[9:0] value：0~999

B.10 STATUS

TBD

B.11 Fault Diagnosis

TBD

B.12ASCII code in GPSRMC Packet

GPSRMC register reserve 86byte, it can store the whole GPSRMC message from GPS module in to the register in ASCII code.

Appendix C ▪ RSView

This appendix gets you started with RSView. It shows you how to use the application to acquire, visualize, save, and replay sensor data.

You can examine sensor data with other free tools, such as Wireshark or tcp-dump. But to visualize the 3D data, use RSView. It's free and relatively easy to use.

C.1 Features

RSView provides real-time visualization of 3D LiDAR data from RoboSense LiDAR sensors. RSView can also playback pre-recorded data stored in "pcap" (Packet Capture) files, but RSView still does not support .pcapng files.

RSView displays distance measurements from a RoboSense LiDAR sensor as point data. It supports custom-colored display of variables such as intensity-of-return, time, distance, azimuth, and laser ID. The data can be exported as XYZ data in CSV format. RSView is not intended to generate point cloud files in LAS, XYZ, or PLY formats.

Functionality and features include:

- Visualize live streaming sensor data over Ethernet
- Record live sensor data in pcap files
- Visualize sensor data from a recording (pcap file)
- Interprets point data such as distance timestamp, azimuth, laser ID, etc.
- Tabular point data inspector
- Export to CSV format
- Ruler tool
- Display multiple frames of data simultaneously (Trailing Frames)
- Display or hide subsets of lasers
- Crop views

C.2 Install RSView

Installer for RSView is provided for Windows 64-bit system and it has no need for other dependencies. You can find the executable installer **RSView_X.X.X_Setup.exe** from the U disk in the RS-LiDAR-16 box. Also you can downlaod the latest version from RoboSense website (http://www.robosense.ai/web/resource/en). Launch the installer and follow the on-screen instructions to finish the installation.

C.3 Set up Network

As mentioned in the RS-LiDAR-16 User's Manual, the default IP address of the computer should be set as 192.168.1.102, sub-net mask should be 255.255.255.0. You should make sure that RSView dose not be shielded by firewall in the computer.

C.4 Visualize Streaming Sensor Data

1. Connect the sensor to your computer and power it up.
2. Start the RSView application.
3. Click on **File** > **Open** and select **Sensor Stream** (Fig C-1).

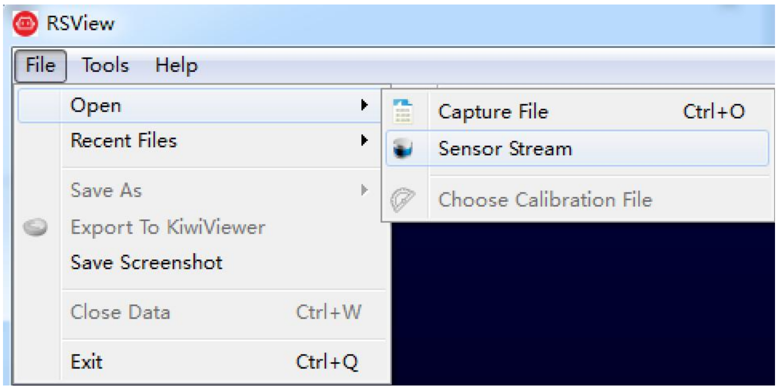


Fig C-1 RSView Open Sensor Stream

4. The Sensor Configuration dialog will appear. The application contains a default configuration folder of RSLIDAR-16 called "RSlidar16CorrectionFile" for reference, but please add the right configuration files folder of the RSLIDAR-16 you have, or you will get chaos point cloud display with the default configuration files. Select the configuration files folder of your lidar and then click **OK** (Fig C-2). The path of the folder should only include English characters and should include all three csv files (angle.csv, ChannelNum.csv, curves.csv). You can find the configuration files folder named "configuration_data" in the U disk in the RS-LiDAR-16 package box or you can ask the RoboSensesupport to get the files.

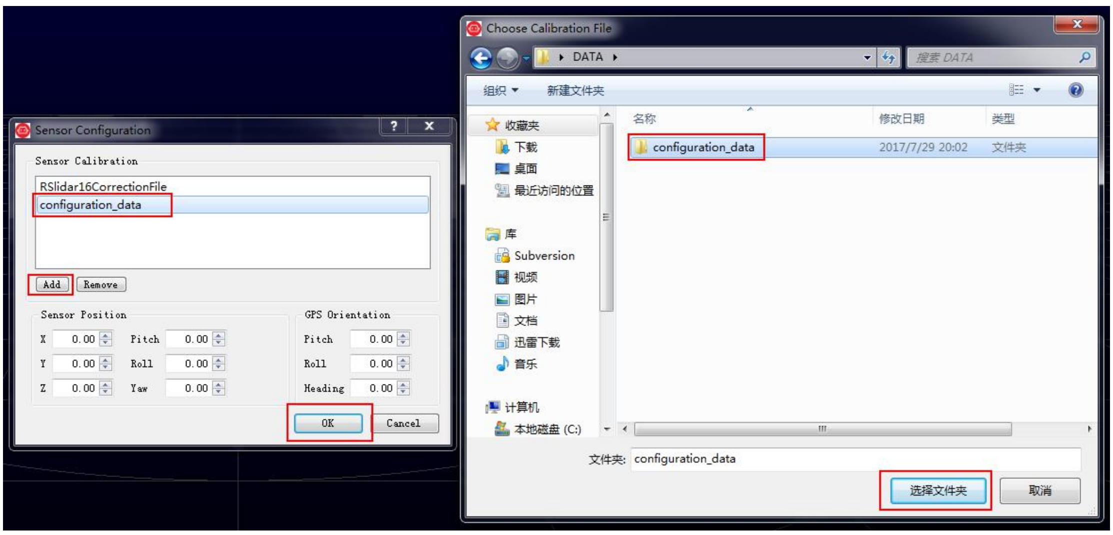


Fig C-2 RSView Select Sensor Correction File

5. RSView begins displaying the sensor data stream (Fig C-3). The stream can be paused by pressing the **Play**

button. Press it again to resume streaming.

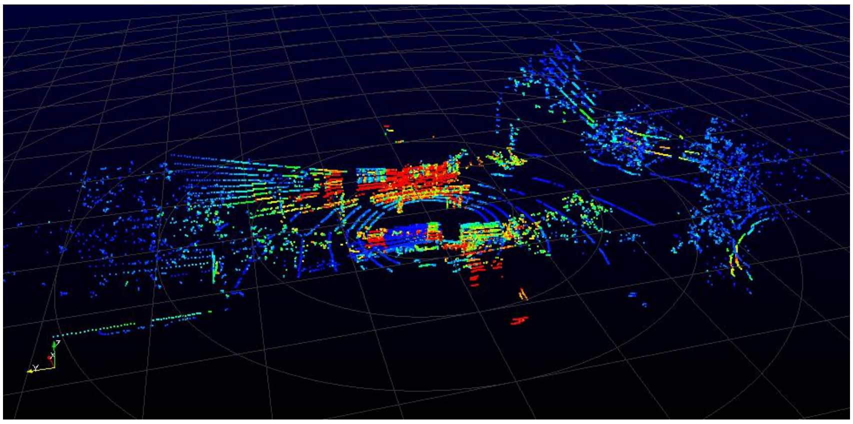


Fig C-3 RSView Sensor Stream Display

C.5 Capture Streaming Sensor Data to PCAP File

1. Click the **Record** button when streaming (Fig C-4).

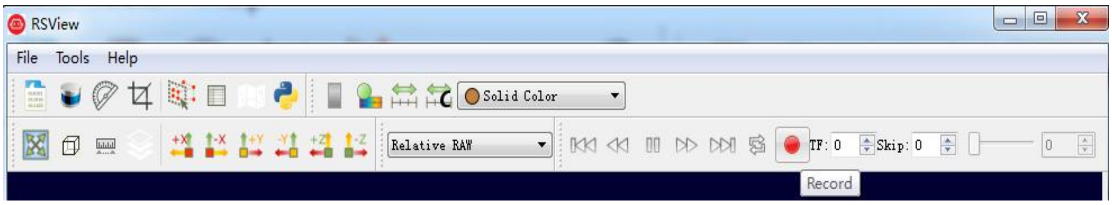


Fig C-4 RSView Record Button

2. A Choose Output File dialog will pop up. Navigate to where you want the file to be saved and click the **Save** button (Fig C-5). RSView begins writing packets to your pcap file. (Note: RS-LiDAR-16 sensors generate a lot of data. The pcap file can become quite large if the recording duration is lengthy. Also, it is best to record to a fast, local HDD or SSD, not to a slow subsystem such as a USB storage device or network drive.)

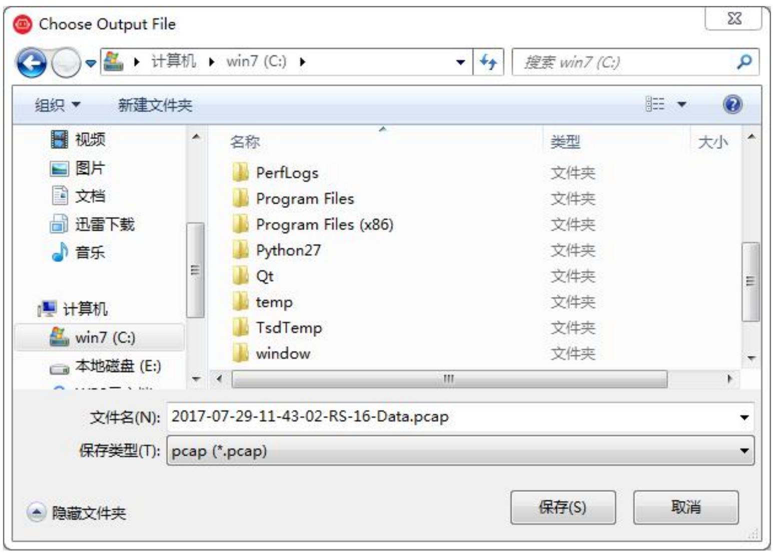


Fig C-5 RSView Record Saving Dialog

3. Recording will continue until the **Record** button is clicked again, which stops the recording and closes the pcap file.

C.6 Replay Captured Sensor Data from PCAP File

To replay (or examine) a pcap file, open it with RSView. You can press **Play** to let it run, or scrub through the data frames with the Scrub slider. Select a set of 3D rendered data points with your mouse and examine the numbers with a Spreadsheet sidebar.

1. Click on **File** > **Open** and select **Capture File** (Fig C-6).

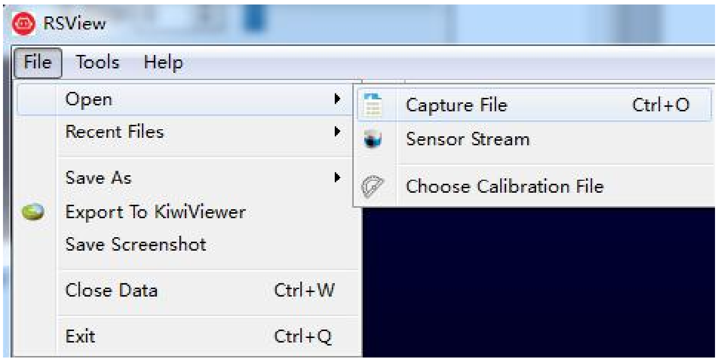


Fig C-6 RSView Open Capture File

2. An Open File dialog will pop up. Navigate to a pcap file, select it, and click the **Open** button.
3. The Sensor Configuration dialog will pop-up. Select your sensor configuration folder and click **OK**.
4. Press **Play** to replay/pause the data stream. Use the Scrub slider tool (it looks like an old-fashioned volume slider) to move back and forth through the data frames. Both controls are in the same toolbar as the **Record** button (Fig C-7).

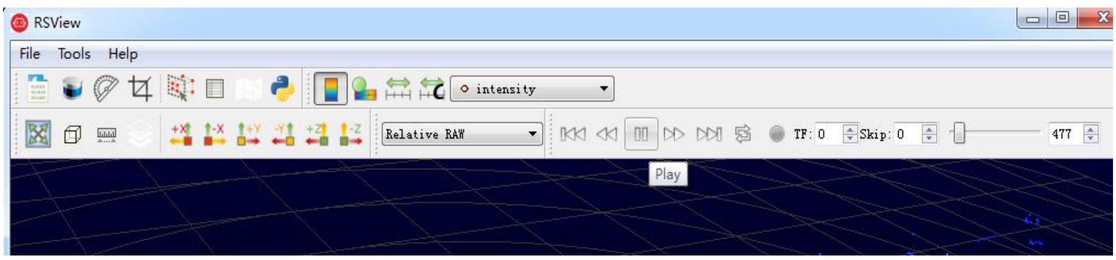


Fig C-7 RSView Play Button

5. To take a closer look at some data, scrub to an interesting frame and click the Spreadsheet button (Fig C-8). A sidebar of tabular data is displayed to the right of the rendered frame, containing all data points in the frame .

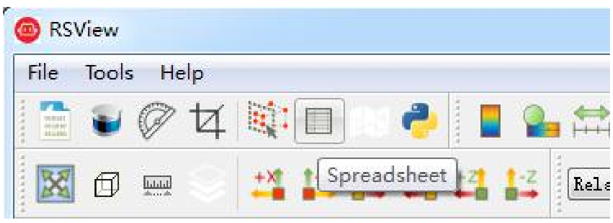


Fig C-8 RSView Spreadsheet Tool

6. Adjust the columns to get a better view of the numbers. If you've adjusted columns in Excel, some of this will be familiar. You can change column widths by dragging the column header divider left or right, and by double-clicking them. Drag column headers left or right to reorder them. Sort the table by clicking column headers. And you can make the table itself wider by dragging the table's sides left or right. Make Points_m_XYZ wider to expose the XYZ points themselves.

Showing: Data | Attribute: Point Data | Precision: 3

	Point ID	Points_m_XYZ	adjustedtime	azimuth	distance_m	intensity	laser_id	timestamp
0	0	0.003...	12320919.000	3	6.170	1	0	12320919
1	1	0.005...	12320922.000	4	7.600	3	1	12320922
2	2	0.008...	12320925.000	5	9.210	2	2	12320925
3	3	0.012...	12320928.000	6	11.520	1	3	12320928
4	4	0.108...	12320958.000	17	36.690	1	13	12320958
5	5	0.022...	12320969.000	21	6.160	1	0	12320969
6	6	0.029...	12320972.000	22	7.660	3	1	12320972
7	7	0.036...	12320975.000	23	9.230	3	2	12320975
8	8	0.048...	12320978.000	24	11.520	1	3	12320978
9	9	0.222...	12321008.000	35	36.540	2	13	12321008
10	10	0.041...	12321019.000	39	6.170	1	0	12321019
11	11	0.052...	12321022.000	40	7.650	2	1	12321022

Fig C-9 RSView Data Point Table

7. Click **Show only selected elements** in the Spreadsheet (Fig C-10). Since no points are selected yet, the table will be empty.

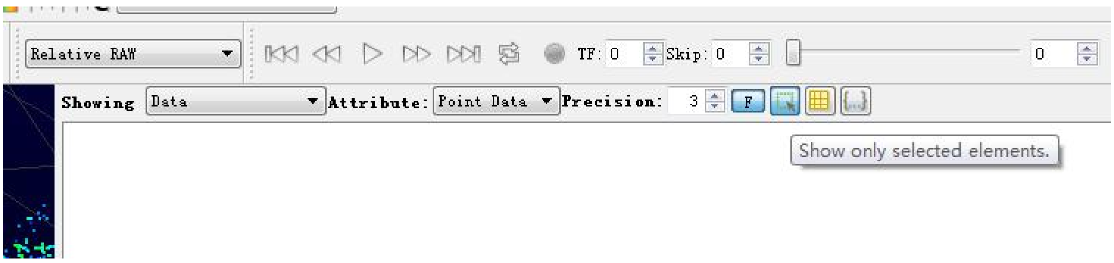


Fig C-10 RSView Show Only Selected Elements

8. Click the **Select All Points** tool. This turns your mouse into a point selection tool(Fig C-11).

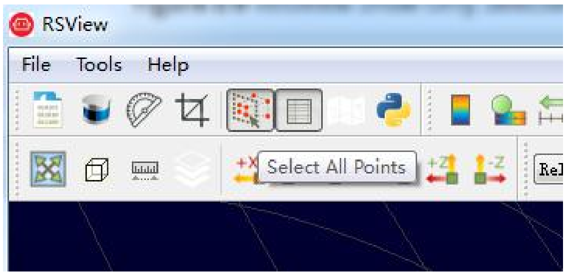


Fig C-11 RSView Select All Points

9. In the 3D rendered data pane use your mouse to draw a rectangle around a small number of points. They will immediately populate the data table (Fig C-12).

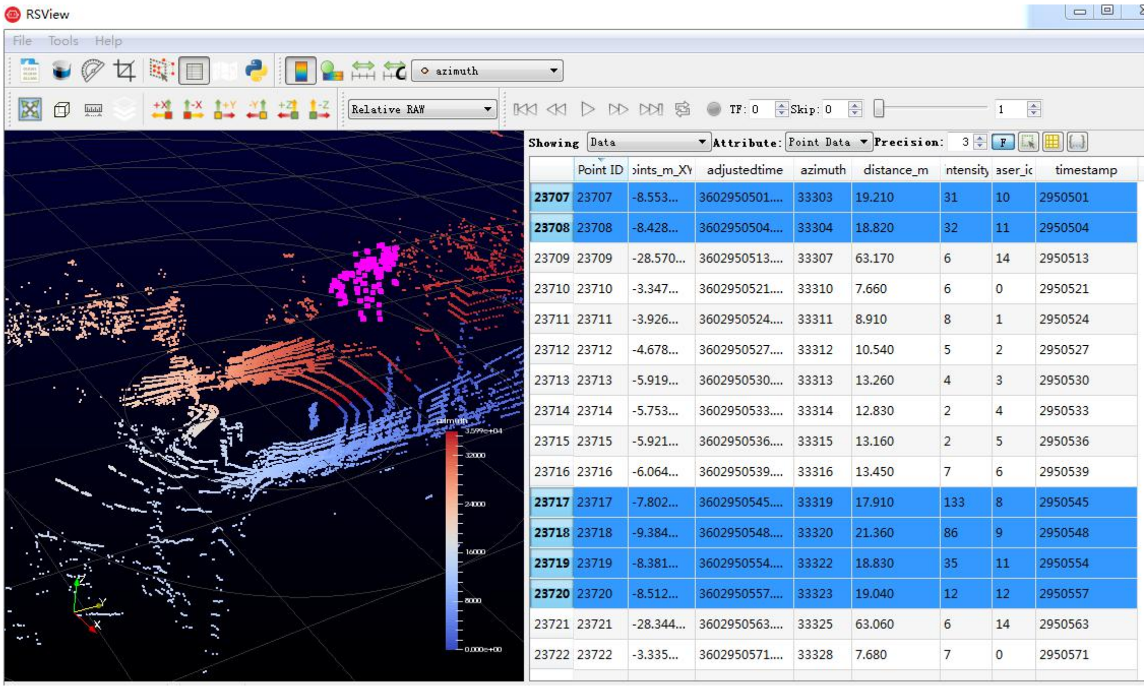


Fig C-12 RSView List Selected Points

10. At any point you can save a subset of data frames by doing **File > Save As > Select Frames.**

C.7 RS-LiDAR-16 Factory Firmware Parameters Setting

RSView provide a tool which integrates UCWP function. We can use this tool to modify Rotation Speed, Network and Time in the RS-LiDAR-16 factory firmware

1. We need connect RS-LiDAR-16 to the PC and confirm we can view the real time data. Then click **Tools > RS-LiDAR Information**.

2. A RS-LiDAR Information dialog will appear. Click **Get** button, it will display the current RS-LiDAR-16 parameters setting.

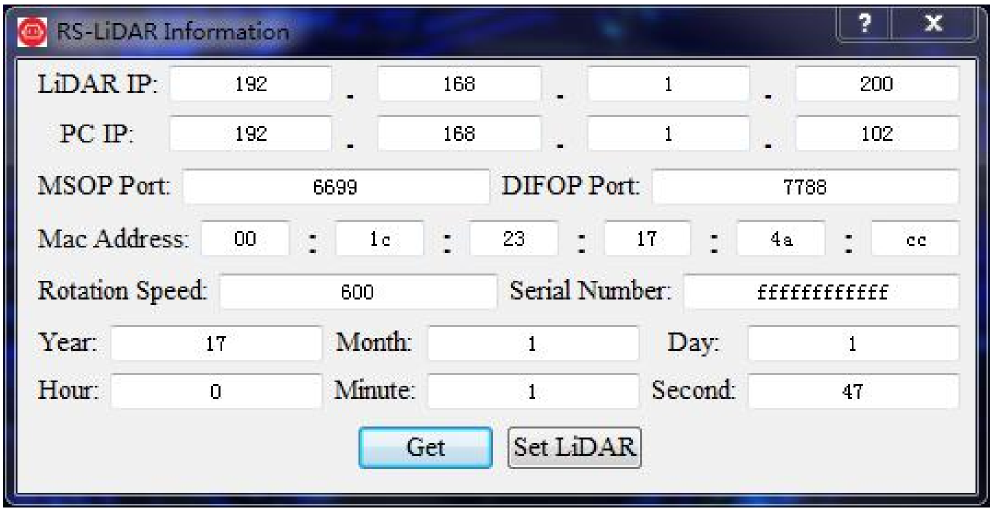


Fig C-13 RS-LiDAR Information

3. We can modify the parameters to the ones we want to have, then click **Set LiDAR**. We need re-power and connect the RS-LiDAR-16 to make the modified parameters valid. After the device connecting again, we can use RSView to see the RS-LiDAR Information again to check if the modification take effect.

Attention: if we modify the PC Port parameters above, we need setting the RSView MSOP Port and DIFOP Port according to C.8 section to make RS-LiDAR-16 can be connected correctly.

C.8 RSView Data Port

In the RS-LiDAR-16 factory firmware, the default MSOP port is 6699, the default DIFOP port is 7788, if we change the RS-LiDAR-16 ports number by modify the 2 parameters in C.7 section, we need configure the RSView Data Port first or we will see nothing in the RSView. If we do not know the RS-LiDAR-16 ports configuration, we can use Wireshark to capture the packets to check the Dst Port.

Click **Tools > Data Port**, enter the real MSOP port and DIFOP port of RS-LiDAR-16, then click **Set Data Port**. After that we can see the cloud point data again in the RSView.

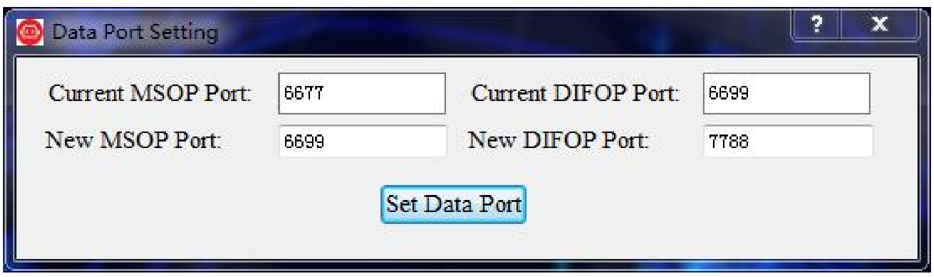


Fig C-14 Data Port Setting

Appendix D ▪ RS-LiDAR-16 ROS Package

This appendix describes how to use ROS to view the RS-LiDAZR-16 data.

D.1 Prerequisite

1. Install Ubuntu 14.04. Please download from ubuntu website and install the ubunut 14.04.
2. Please refer the link (http://wiki.ros.org/indigo/Installation/Ubuntu) to install the ROS indigo version.

D.2 Install RS-LiDAR-16 ROS Package

1. Create the work space for ros:

```
cd ~

mkdir -p catkin_ws/src
```

2. Copy the ros_rslidar_package into the work space ~/catkin_ws/src. You can find the ros_rslidar package in the U disk in the RS-LiDAR-16 box. You can also ask RoboSense

3. Build

```
cd ~/catkin_ws

catkin_make
```

D.3 Configure PC IP address

For the default RS-LiDAR-16 firmware, it is configured the "192.168.1.200" as its own IP address, and the "192.168.1.102" as its destination PC IP address. So we need set the PC static IP as "192.168.1.102" and the net mask as "255.255.255.0", while the gateway address is not necessary. After configuration, we can use "ifconfig" command to check if the IP is work.

D.4 View the real time data

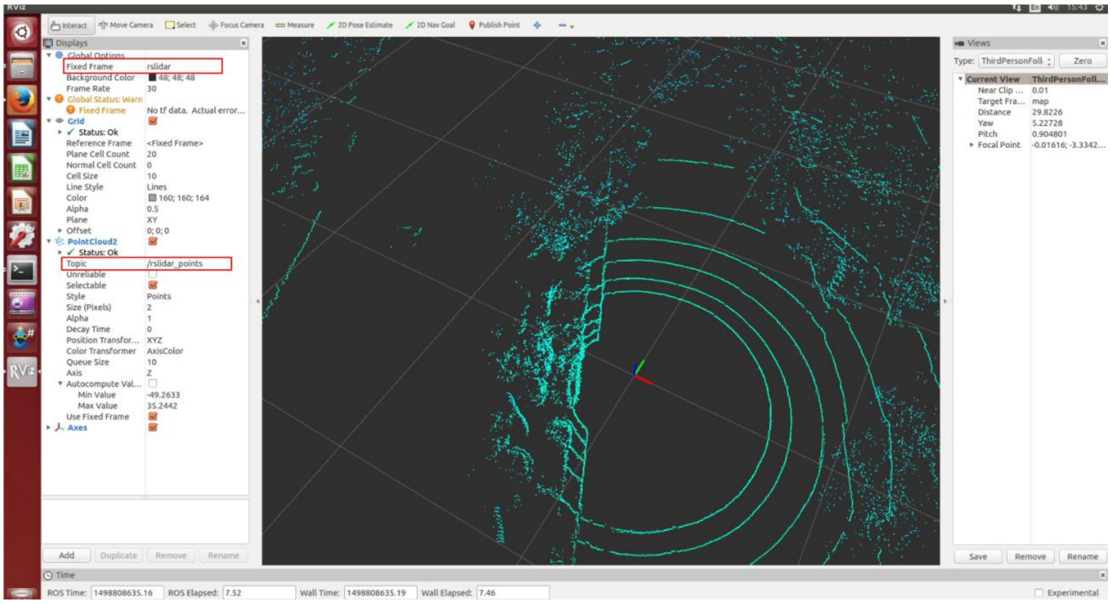
1. Connect the RS-LiDAR-16 to your PC via RJ45 cable, and power on it.
2. We have provided an example launch file named "**one.launch**" under rslidar_pointcloud/launch ro start the node, we can run the launch file to view the real time point cloud data. Open an teminal:

```
cd ~/catkin_ws

source devel/setup.bash

roslaunch rslidar_pointcloud one.launch
```

3. Open a new terminal:

```
rviz
```

Set the Fixed Frame to "rslidar". Add a Pointcloud2 type and set the topic to "rslidar_points":



D.5 View the recorded pcap file offline

We can also use the ros_rslidar ROS package to view the recorded .pcap data.

1. Modify the “**one.launch**” file to something like below (please pay attention to the red line):

```
<launch>

  <node    name="rslidar_node" pkg="rslidar_driver" type="rslidar_node" output="screen" >

    <param name="pcap" value="the absolute path to your .pcap file"/>

    <!--param name="device_ip" value="192.168.1.200"/-->

    <!-- Set the LiDAR data port on the PC side, default is 6699 -->

    <param name="port" value="6699"/>

  </node>


  <node    name="cloud_node" pkg="rslidar_pointcloud" type="cloud_node" output="screen" >

    <param name="curves_path" value="/data/curves.csv" />

    <param name="angle_path" value="/data/angle.csv" />

    <param name="channel_path" value="/data/ChannelNum.csv" />

  </node>
```

```
</launch>
```

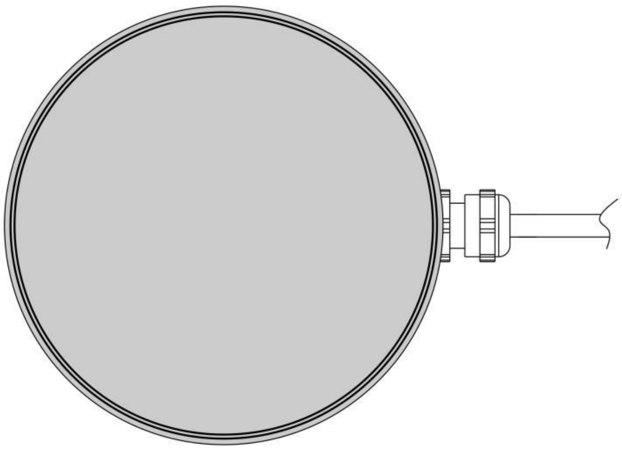
2. Open an teminal:

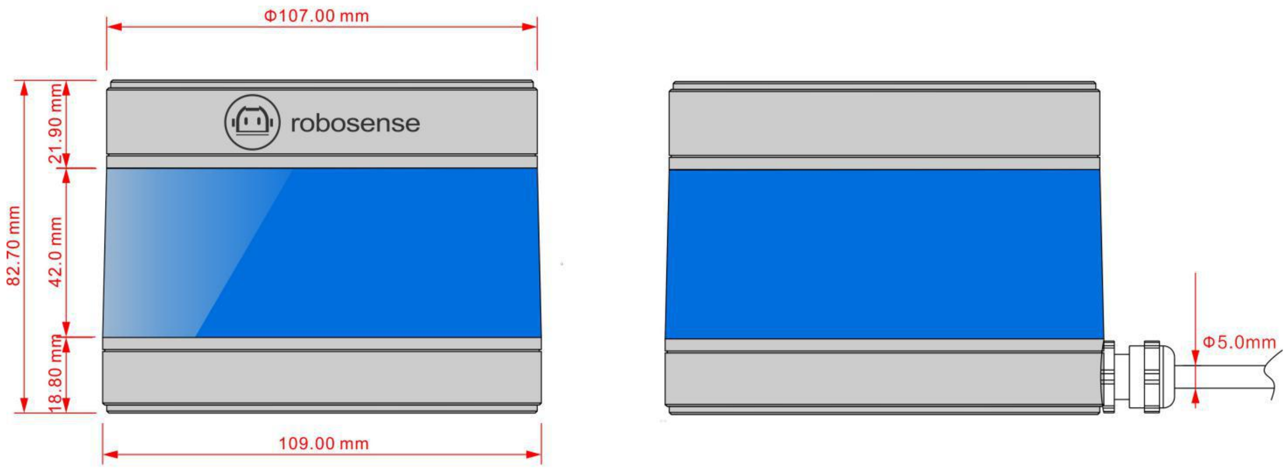
```
cd ~/catkin_ws
source devel/setup.bash
roslaunch rslidar_pointcloud one.launch
```

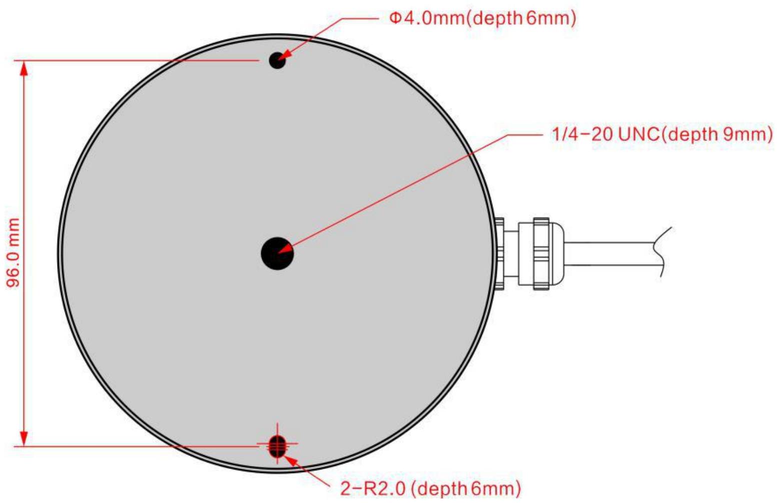
3. Open a new terminal and run：

```
rviz
```

Appendix D ▪ Dimensions







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